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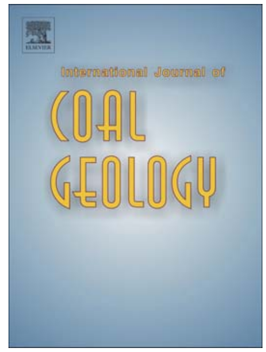

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Lateral development of coalification in the Czech part of the Upper Silesian Coal Basin and its connection with gas deposits

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Abstract

The degree of coalification is an essential parameter influencing the quality of coal reserves. Modelling of the development of this parameter in the Czech part of the Upper Silesian Coal Basin (Carboniferous, Mississippian to Pennsylvanian - Lower Namurian to Westphalian A) revealed the distribution of coalification within the basin in all its stratal units. The grade of coalification was found in principle to be similar but its intensity in general decreases upwards into the hanging wall. Because of different areal extents of individual stratal units the degree of coalification is demonstrated on the oldest and areally most extensive unit - the Petřkovice Member. The studies and their results presented in this paper are based on more than 29,000 analyses of the dry and ash-free volatile matter (V^{daf}) in coal samples from surface and underground boreholes drilled in the years 1946 - 2000. Three zones of enhanced coalification were distinguished: the Ostrava-Příbor Zone, the Rožnov-Frenštát Zone and the Příbor-Těšín Zone. These zones were found to correlate fairly well with the occurrence of gas deposits confined to the weathered Carboniferous rock massif or its mantle. Consequently, the degree of coalification does not only determine the quality of coal reserves but may also be used as an auxiliary tool in the search for gas deposits in coal basins.

Keywords:
Carboniferous; Upper Silesian Coal Basin; Czech Republic; Coalification; Volatile matter contents; Gas generation

1. Introduction and geological setting

The Upper Silesian Coal Basin (hereinafter referred to as USCB) with bituminous coal deposits was formed in final stages of the evolution of the extensive Moravo-Silesian Paleozoic Basin in the eastern block of the Central European Variscides. It was formed in the foreland of the Variscan orogen and became a part of its outer zones, the Rhenohercynicum and Subvariscicum (Grygar and Vavro, 1995; Fig. 1). In this aspect, the USCB occupies a similar structural position as other European bituminous coal basins aligned in a belt stretching from the British Isles across Germany and Poland to the eastern part of the European Variscides. The latter unit is exposed here to the surface (including its internal zones of Moldanubicum and Saxothuringicum), giving rise to the Bohemian Massif.

The Upper Silesian Coal Basin, in its post-erosional limits, has a subtriangular outline reaching from Poland to the Czech territory with its southern extension. In its areal extent, this significant European bituminous coal basin exceeds 7000 km^2, of which 1550 km^2 lie in the territory of the Czech Republic. The remaining, larger part lies in the territory of neighbouring Poland.

The Czech part of the USCB is located within the Moravo-Silesian region of the Bohemian Massif. The basin fill represents some of the youngest sediments overlying the Brunovistulicum (Kalvoda et al., 2008), post-dating the main phases of the Variscan orogeny, and deposited from approx. Upper Carboniferous onwards. The basin floor is formed by older sedimentary cover of the Brunovistulicum: Devonian and Lower

Carboniferous sediments. The basin fill is overlain by Neogene deposits of the Carpathian Foredeep and – further south – also by nappes of the Outer Carpathians.

The western limit of the Czech part of the USCB is a post-erosional (Fig. 2), defined by the contact with the underlying Lower Carboniferous sediments. The NE limit is defined by the state border with Poland. The southern boundary of the basin is not clearly defined as the coal-bearing sediments of the basin dip south beneath thick nappe complexes of the Carpathians. This paper places the southern limit at the fault zone of the Beskydy Mts.; in its southern limb, the coal-bearing sediments plunge into depths of over 1 km below the surface.

Geology of the Czech part of the USCB has been described in a number of published papers as well as unpublished reports. In one of the most recent papers, Dopita et al. (1997) summarized the existing knowledge of the geology of the basin, including a description of the lithostratigraphic subdivision of the Carboniferous fill of the USCB (Fig. 3), also followed in the present paper. Chemical-technological parameters of the coal seams were covered mostly in unpublished studies and reserves calculations for the individual mining areas and exploration fields. Recently, they were described in the monograph by Sivek et al. (2003). Properties of coal matter are newly discussed in a monograph edited by Martinec et al. (2005). Validity of Hilt's law in the coal seams in the Czech part of the USCB was investigated by Sivek et al. (2008). Available studies on the USCB geology in English from the 1990s include, e.g., Dopita and Kumpera (1993) and Kumpera (1997).

In the present paper, the degree of coalification is studied using the volatile matter contents of the coals. The authors are aware that the study of coalification would be better justified by data on maximum vitrinite reflectance R_{max} (Thomas, 2002). This parameter, however, started to be monitored in the Czech part of the USCB only in the final stages of basin exploration, and vitrinite reflectance was measured in only a few exploration fields and mining areas. The respective data are missing from absolute majority of the Czech part of the basin, and cannot be acquired additionally. Neither the number of vitrinite reflectance measurements taken, nor the distribution of data would therefore provide an idea of basin-wide 3-D trends in coalification. In contrast, volatile matter contents were determined in all samples taken. Justification of the use of V^{daf} for works in the USCB was documented by the paper of Honěk and Martinec (1999) who proved a very good correlation between V^{daf} and mean vitrinite reflectance R_o for various types of coals in the USCB and published the separate correlation curves and formulae of regression dependencies between the two parameters.

2. Methods

The study deals with the Ostrava–Karviná and the Beskydy Piedmont parts of the USCB (Fig. 2). It does not cover Namurian coal-bearing sediments found in boreholes in the area of the Němčičky Basin, regarded as a southern continuation of the USCB by some authors (Suk et al., 1991; Kumpera, 1997). Thus, in this study, the zone of the Beskydy Mts. Fault, to the south of which the coal-bearing sediments plunge to the depth of more than a kilometre under the surface, is considered the southern boundary (in accordance with the study of Dopita et al., 1997).

When undertaking this study, results of more than 29,000 chemical-technological analyses of coal seams were used. They come mostly from exploratory boreholes. Geological exploration, including exploratory boreholes, was performed systematically in the area of the basin, one deposit after another, over a relatively long time period (1946–2000). This fact, the consequences of which cannot be eliminated at present, had to be taken into account at the selection of evaluated parameters and also at the evaluation itself of the obtained results.

Sampling of drill cores and of the coal matter they yielded was guided by standards effective for the respective time period. The numbers of analyses in the separate boreholes differ, depending on the numbers of encountered coal seams.

The dry and ash-free volatile matter (V^{daf}) values served for the construction of developmental models for the separate stratal units and basin segments. These models form the basis of this study.

The essential material for the elaboration of this study was a set of maps showing the volatile matter dry and ash-free contents *(V^{daf})* in the individual stratal units. The maps were complemented by cross-sections containing information on vertical trends in coalification and enabling a comparison among coalification values in separate layers. The construction of the coalification maps, which are basically contour maps, and of the cross-sections employed the InRoadsSide software of the Bentley Systems, Inc. Visualization in maps was mediated by the MicroStation software product of the same company. The necessary statistical analyses were performed with the use of program module of the Surfer software of Golden Software, Inc.

The regression function for the vitrinite bituminous coal of Ostrava Formnation (vitrinite ≥ 70 % and liptinite ≤ 10 %) according to Honěk and Martinec (1999) is mathematically a polynominal of the 4th degree: $y = 0.0000001x^4 - 0.0000528x^3 + 0.0041009x^2 - 0.1519725x + 3.2616854$, where y stands for estimation mean value of vitrinite reflectance R_o (%), x stands for determined value of volatile matted V^{daf} (%) in bituminous coal with ash content $A^d < 10$ %. Coefficient of correlation R = 0.9981139.

3. Results

As has been stated above, sediments of the USCB represent a post-erosional relic of a formerly undoubtedly much larger basin. Therefore, younger stratal units are now of a smaller areal extent than older units (Fig. 4). Lateral trends in the coalification degree in the basin can be thus best observed in the oldest stratal unit of coal-bearing Carboniferous sediments in the Czech part of the USCB – the Petřkovice Member (Fig. 5).

Three zones of elevated coalification degree were delineated based on the maps of the trends in volatile matter contents constructed for the individual stratal units (Fig. 6). These zones were designated as the Ostrava–Příbor Zone, Rožnov–Frenštát Zone and the Příbor–Těšín Zone and contoured at the level of the Petřkovice Member with respect to the smaller post-erosional extent of younger stratal units.

(1) The **Ostrava–Příbor Zone** is undoubtedly the area of the highest coalification degree in the basin. It is elongated NNE–SSW, with a post-erosional western limit defined by the boundary against the underlying Kyjovice Member of Lower Carboniferous age. The effects of the Variscan orogeny increase in intensity towards the west (or WNW) in the Ostrava–Příbor Zone. This is reflected by an increase in the coalification degree (and a decrease in the volatile matter contents). These changes are very intensive, manifested by a decrease in the volatile matter contents down to values locally reaching the anthracite rank for coal in the respective parts of the coal seams (volatile matter contents of 2.5 % – 17.0 %). Nevertheless, the intensity of coalification in this zone decreases not only towards the ESE, but also towards the S and SSW. The area of high values of the coalification degree ends in this direction. This would mark an end of the Ostrava–Příbor Zone, which passes into the Rožnov–Frenštát Zone in this area.

(2) The **Rožnov–Frenštát Zone** is elongated – unlike the Ostrava–Příbor Zone – in the direction WNW–ESE. The degree of coalification of its coal seams is lower than in the Ostrava–Příbor Zone. The eastern part of the zone is imperfectly known due to the lower density of exploratory works. In spite of this, the intensity of the coalification degree can be interpreted as decreasing towards the east. This zone is much less distinct than the Ostrava–Příbor Zone. It is best manifested in the lowermost stratal unit of the Petřkovice Member, but is much less distinct in the overlying Hrušov Member already. Its character in younger stratal units cannot be precisely traced due to their present, erosively reduced development practically not extending to the area of the Rožnov–Frenštát Zone. The Rožnov–Frenštát Zone lies between the Janovice Fault and the Beskydy Piedmont Fault Zone, with which it probably preferentially merges.

(3) The **Příbor–Těšín Zone** runs WNW–ESE, being more or less subparallel to the Rožnov–Frenštát Zone. The coalification degree in this zone is, similar to the Rožnov–Frenštát Zone, i.e. much lower compared to that in the Ostrava–Příbor Zone. The Příbor–Těšín Zone is equally traceable especially in the lowermost stratal unit of the Petřkovice Member and becomes less distinct in the Hrušov Member. Its character in younger stratal units cannot be precisely traced due to their present small extent reduced by erosion.

4. Discussion

4.1 . Geological controls and trends of the coalification

Temperature, pressure and time of exposure of coal seams to these phenomena are generally considered to be the principal factors governing the process of coalification in coal basins (e.g., Teichmüller, 1987). However, the grade of coalification in the Czech part of the USCB resulted from a combination of more factors such as the depth of burial of coal seams in particular, which corresponds with Hilt's law in this basin that was confirmed by, e.g., Weiss (1980) and Sivek at al. (2008). As follows from areal variations in rank of coal and fluctuation in its vertical development it is apparent that tectonics (Petránek and Dopita, 1955), influx of heat in front of an orogenic front or close to magmatic intrusions (Dvořák and Wolf, 1979; Francu et al. 2002) and even fossil weathering (Klika et al., 2004) have played important roles in the process of coalification. The extent and effects of these processes are presently being studied. The effect of these phenomena on the degree of coalification is also known from other European and world basins (Hower and Gayer, 2002). For instance, the influx of heat in front of an advancing orogenic front as an essential factor influencing the rank of coal has also been reported from the Northern Eifel, Rhenisch Massif, Germany (Ribbert and Vieth, 2005), Ruhr basin, Germany (Littke et al., 1994) or from the South Wales Basin, Great Britain (Gayer et al., 1998).

4.2 . Technical-economic consequences of the coalification degree in coal basins

The knowledge of the distribution of coalification intensity in basins apart from the understanding of qualitative properties of coals also provide noteworthy information for prospecting and exploration of deposits of natural gas in sediments overlying the coal basins or at contact between these coal-bearing sediments and the overlying sedimentary complexes. Gases in these deposits are genetically linked with the coalification processes in the coal seams. The origin of such deposits, as it appears, is favoured by those parts of coal basins where coal seams were subjected – besides pre-orogenic coalification – also to post-orogenic phases of coalification processes. At the same time, the coalification degree in these zones must lie within optimum limits for the natural gas formation. For example, the optimum values of mean vitrinite reflectance for the formation of gas deposits in the hangingwall of coal-bearing Carboniferous sediments were established at R_m = 1-2 % (alternatively 2-3 %) by Teichmüller (1986). These values roughly correspond to V^{daf} values of 12-30 % (alternatively 8-12 %). In the Czech part of the USCB, analogous conditions can be found in the areas of the Ostrava–Příbor Zone, or in the Příbor–Těšín Zone. Spatial relation of known natural gas deposits in the Czech part of the USCB to the areal distribution of the coalification degree in the basin is shown in Fig. 7. The figure implies a clear correlation between the spatial distribution of the two cited zones of elevated coalification and locations of the known natural gas deposits: most of the deposits lie in the areas of elevated coalification or are in contact with these zones. The only exceptions are small deposits in the Ostrava–Karviná Ridge (Stonava – no. 7 at Fig. 7) and the oil and gas deposits of Krásná and Lomná (not given in Fig. 7), which are of a different genetic origin and lie at the contact between the crystalline rocks and the overlying complexes. The origin of these deposits was associated with the incorporation of the Czech part of the USCB into the autochthonous complex of the Carpathian orogen. Natural gas was trapped especially at suitable sites on paleohighs of the weathered surface of Carboniferous rocks. Particularly favourable conditions for the origin of this type of gas deposits existed in the Příbor–Těšín Zone. Optimum conditions for the origin of gas deposits did not exist in the Rožnov–Frenštát Zone. Here, coalification of the upper part of the stratal succession of Carboniferous coal-bearing sediments was of lower intensity than the lower limit of Teichmüller (1986) R_m = 1 % for gas generation. The lower part of the stratal succession in this part of the basin, although exceeding the required limit of coalification intensity, was characterized by a reduction of the individual lithostratigraphic units and contained only few coal seams. These seams could not supply amounts of gas sufficient for the formation of gas deposits during the coalification process. Therefore, no occurrences of major gas deposits can be expected in this part of the basin.

Conclusions made by the present authors in the Czech part of the USCB correspond to those of Teichmüller (1986) from NW Germany: from the Ruhr Basin, Münsterland Basin and the Lower Saxony Basin. Zones subjected to the post-orogenic phase of the coalification process can be viewed, on condition of favourable coalification degree values of coal seams, as promising in the search for natural gas deposits in the overlying sediments or close to the contact between the coal-bearing sediments and the overlying sediments.

Conclusions

Zones of a higher degree of coalification in the USCB can be best observed in the lowermost member of the sequence – the Petřkovice Member (Lower Namurian). Nevertheless, a similar areal distribution of coalification was found to occur also in younger stratal units. Gas deposits occurring in weathered Carboniferous rock massif and its overburden are obviously spatially related to the zones of elevated coalification. This relationship, known from other world coal basins, has also been proved to exist in the Czech part of the USCB.

Acknowledgements

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Figure captions:

Fig. 1. Simplified geological map showing major tectonic zones, geological units and the position of the Upper Silesian Coal Basin.

Fig. 2. Regional subdivision of the Czech part of the Upper Silesian Coal Basin (according to Sivek et al., 2008).

1 – settlements, 2 – state border, 3 – post-erosional boundary of the basin, 4 – major structures, 5 – Upper Carboniferous fill of the basin.

Fig. 3. Lithostratigraphic division of the Czech (CR) and Polish (PR) parts of the Upper Silesian Basin (Sivek et al., 2003).

Fig. 4. Occurrnce of the stratal units in the Czech part of the Upper Silesian Coal Basin.

Fig. 5. A contour map of the dry and ash-free volatile matter contents (V^{daf}) in the Petřkovice Member in the Czech part of the USCB (1 – populated areas, 2 – post-erosional limits of the basin, 3 – state border). Comments: a) occurrence of Carboniferous sediments in the Jablunkov Furrow (vicinity of town Jablunkov) is poorly known and was not evaluated, b) R_o calculated according to Honěk and Martinec (1999).

Fig. 6. Zones of elevated coalification degree in the Czech part of the Upper Silesian Coal Basin (Sivek et al. 2003, adapted). 1 – state border, 2 – post-erosional boundary of the basin, 3 – zone of elevated coalification degree (V^{daf} 3.0 % to 20.0 %) , 4 – zone of elevated coalification degree (V^{daf} 20.0 % to 33.0 %).

Fig. 7. Gas hydrocarbon deposits and zones of elevated coalification in the Czech part of the Upper Silesian Coal Basin. (1 – state border, 2 – post-erosional boundary of the basin, 3 – zone of elevated coalification degree (V^{daf} 2.5 % to 17.0 %), 4 – Zone II of elevated coalification degree (V^{daf} 14.0 % to 20.0 %), 5 – major deposits, 6 – medium-size deposits.

Gas deposits: 1 Žukov, 2 Příbor-Klokočov, 3 Příbor-jih (Štramberk underground gas storage), 4 Bruzovice, 5 Staříč-Lískovec, 6 Krmelín, 7 Stonava, 8 Mitrovice, 9 Lhotka-Pstruží, 10 Hřemanice.

Fig. 1

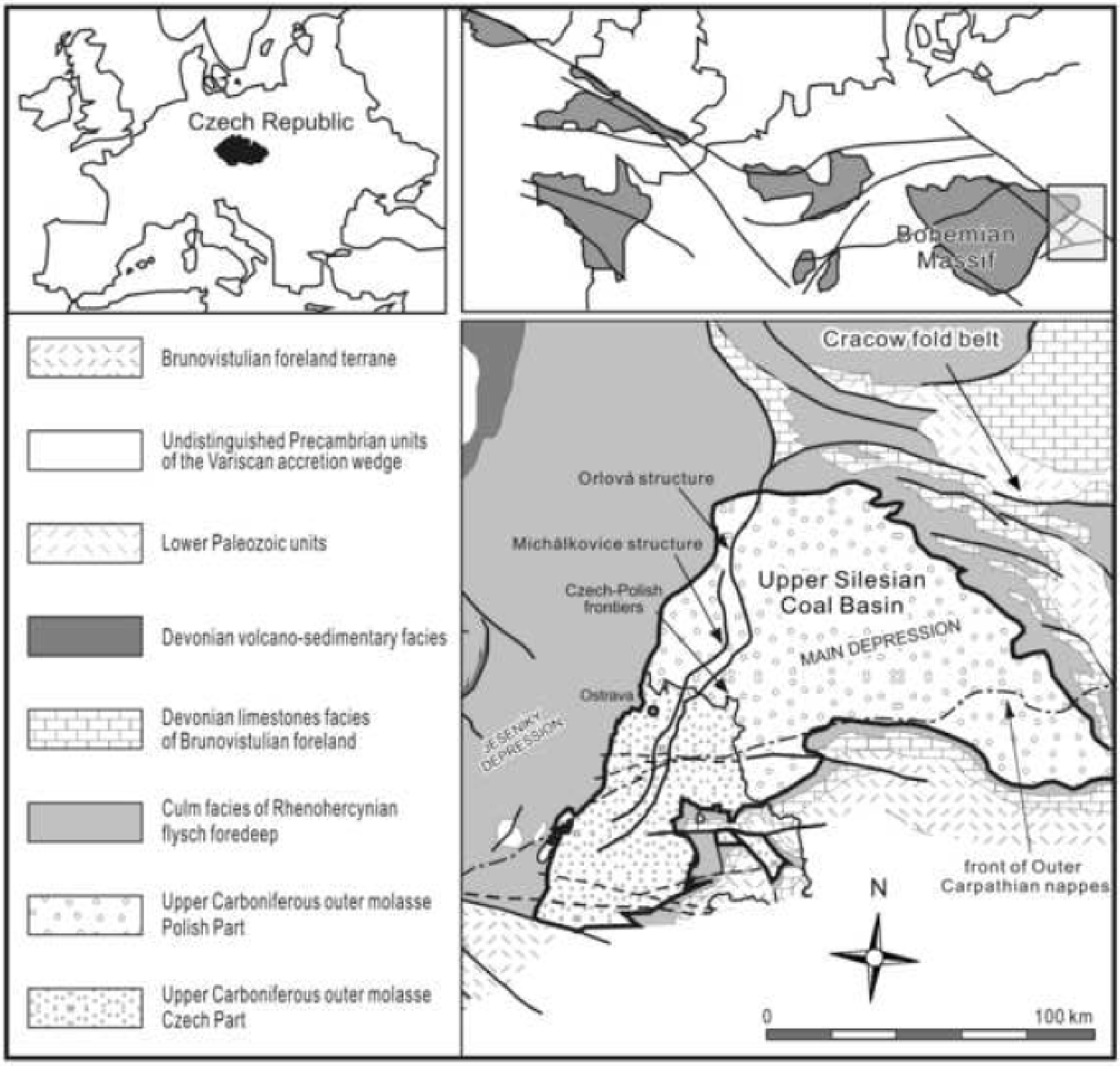
Czech Republic
Bohemian Massif
Brunovistulian foreland terrane
Undistinguished Precambrian units of the Variscan accretion wedge
Lower Paleozoic units
Devonian volcano-sedimentary facies
Devonian limestones facies of Brunovistulian foreland
Culm facies of Rhenohercynian flysch foredeep
Upper Carboniferous outer molasse Polish Part
Upper Carboniferous outer molasse Czech Part
Cracow fold belt
Orlová structure
Michálkovice structure
Czech-Polish frontiers
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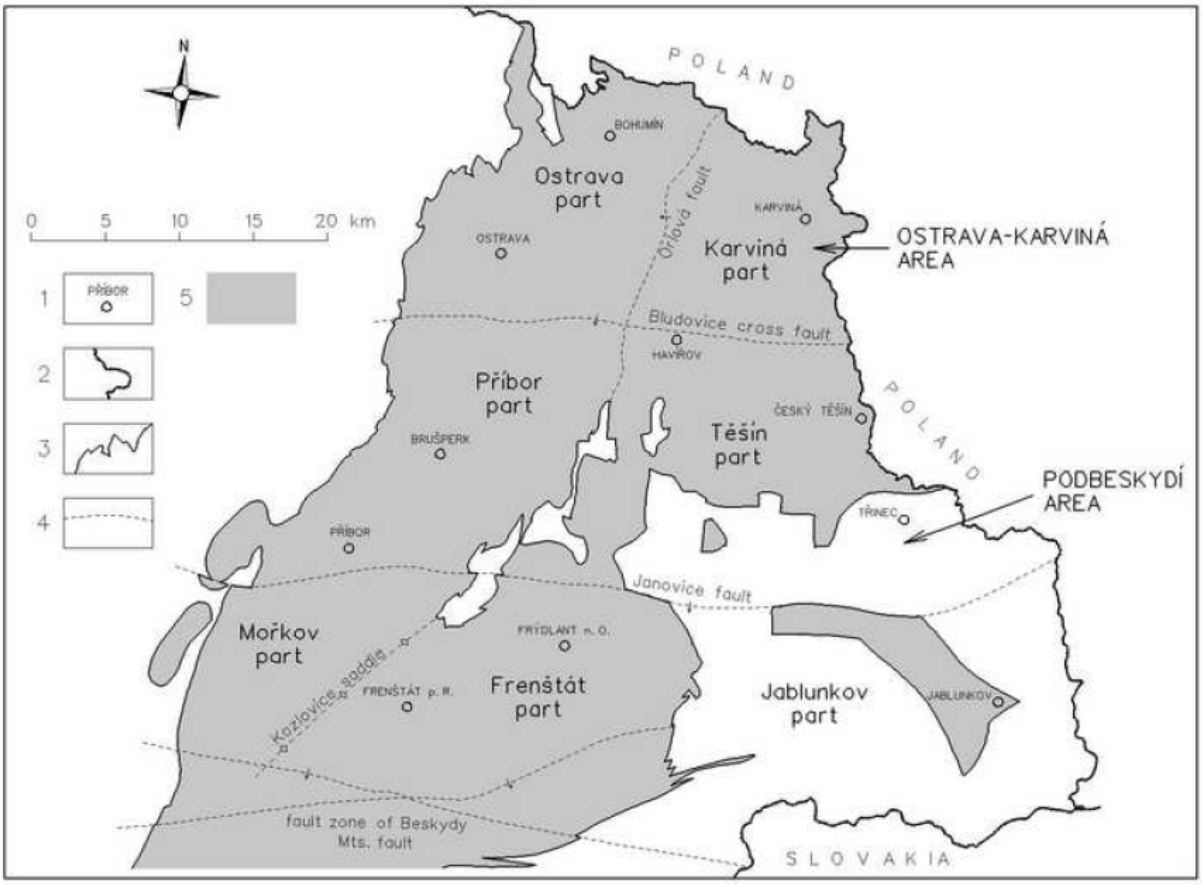
Fig. 2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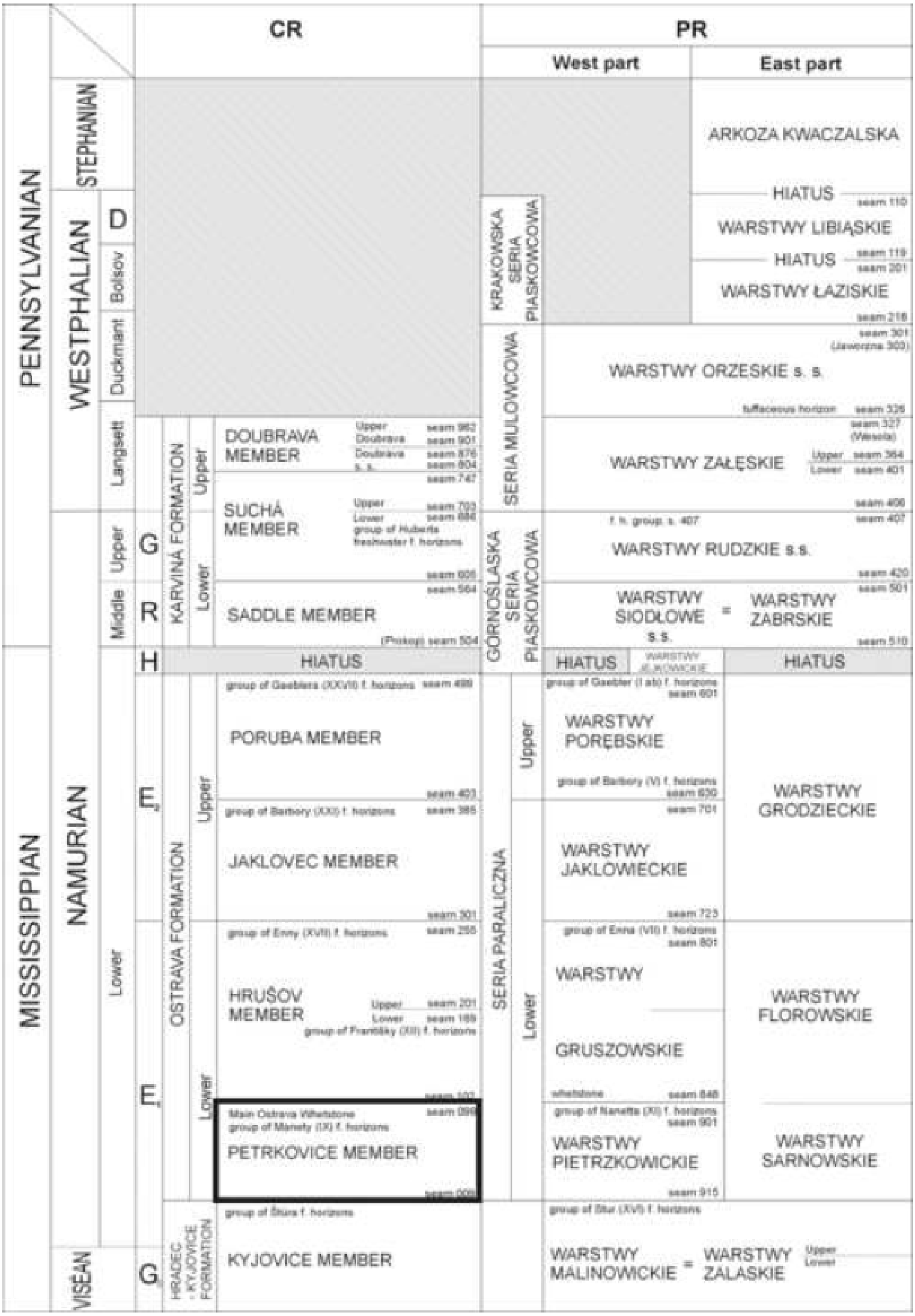
1
PŘÍBOR
5
2
3
4
Bludovice cross fault
HAVÍŘOV
Příbor part
ČESKÝ TĚŠÍN
POLAND
BRUŠPERK
Těšín part
PODBESKYDÍ AREA
TŘINEC
PŘÍBOR
Janovice fault
Mořkov part
FRÝDLANT n. O.
Kozlovice saddle
FRENŠTÁT p. R.
Frenštát part
Jablunkov part
JABLUNKOV
fault zone of Beskydy Mts. fault
SLOVAKIA

Fig. 3


CR
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KARVINÁ FORMATION
OSTRAVA FORMATION
HRADEC - KYJOVICE FORMATION
DOUBRAVA MEMBER
SUCHÁ MEMBER
SADDLE MEMBER
HIATUS
PORUBA MEMBER
JAKLOVEC MEMBER
HRUŠOV MEMBER
PETRKOVICE MEMBER
KYJOVICE MEMBER
KRAKOWSKA SERIA PIASKOWCOWA
SERIA MUŁOWCOWA
GÓRNOŚLĄSKA SERIA PIASKOWCOWA
SERIA PARALICZNA
ARKOZA KWACZALSKA
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WARSTWY ORZESKIE s. s.
WARSTWY ZAŁĘSKIE
WARSTWY RUDZKIE s.s.
WARSTWY SIODŁOWE s.s. = WARSTWY ZABRSKIE
WARSTWY POREBSKIE
WARSTWY JAKLOWIECKIE
WARSTWY GRUSZOWSKIE
WARSTWY PIETRZKOWICKIE
WARSTWY MALINOWICKIE = WARSTWY ZALASKIE
WARSTWY GRODZIECKIE
WARSTWY FLOROWSKIE
WARSTWY SARNOWSKIE

Fig. 4

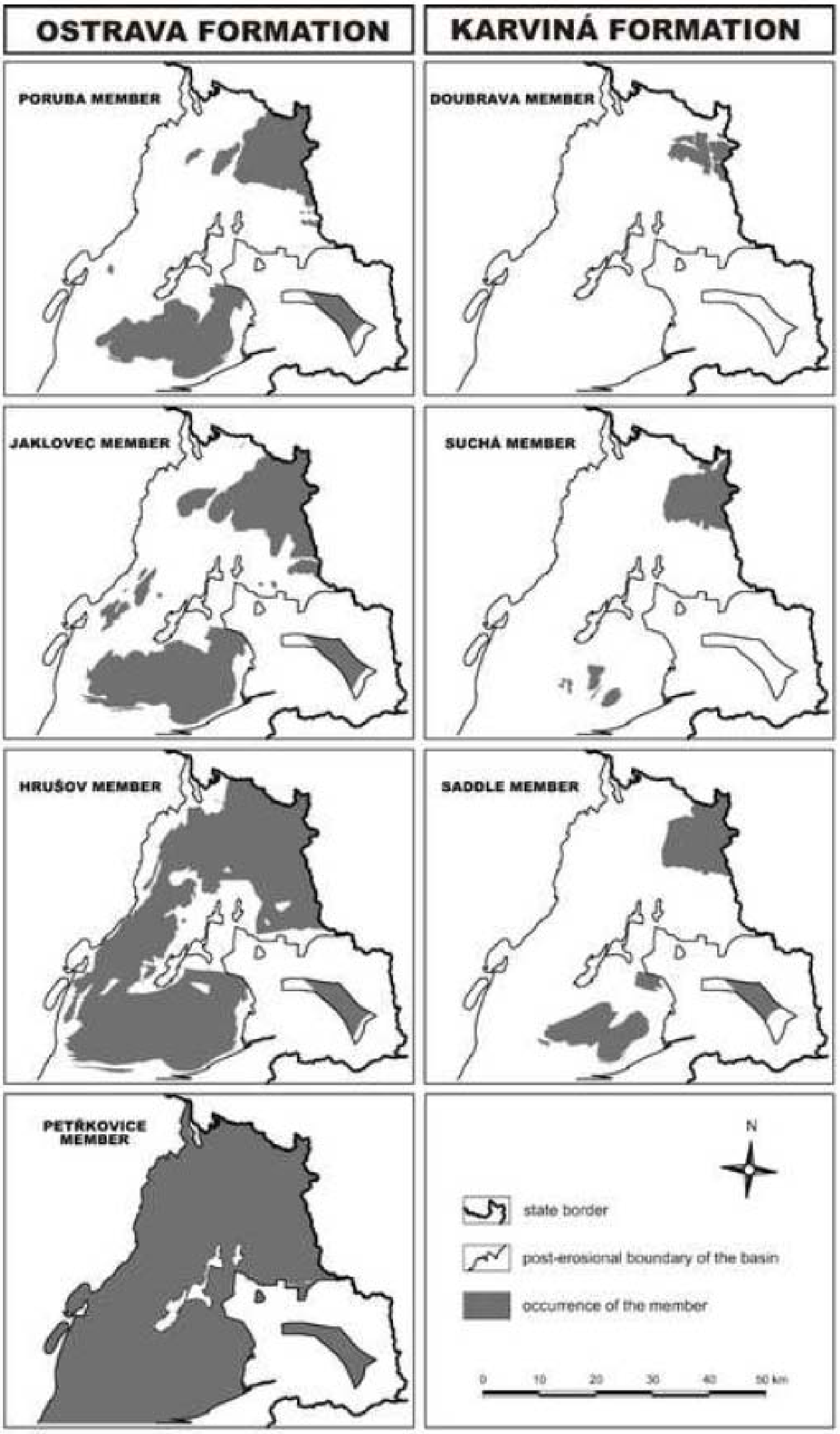
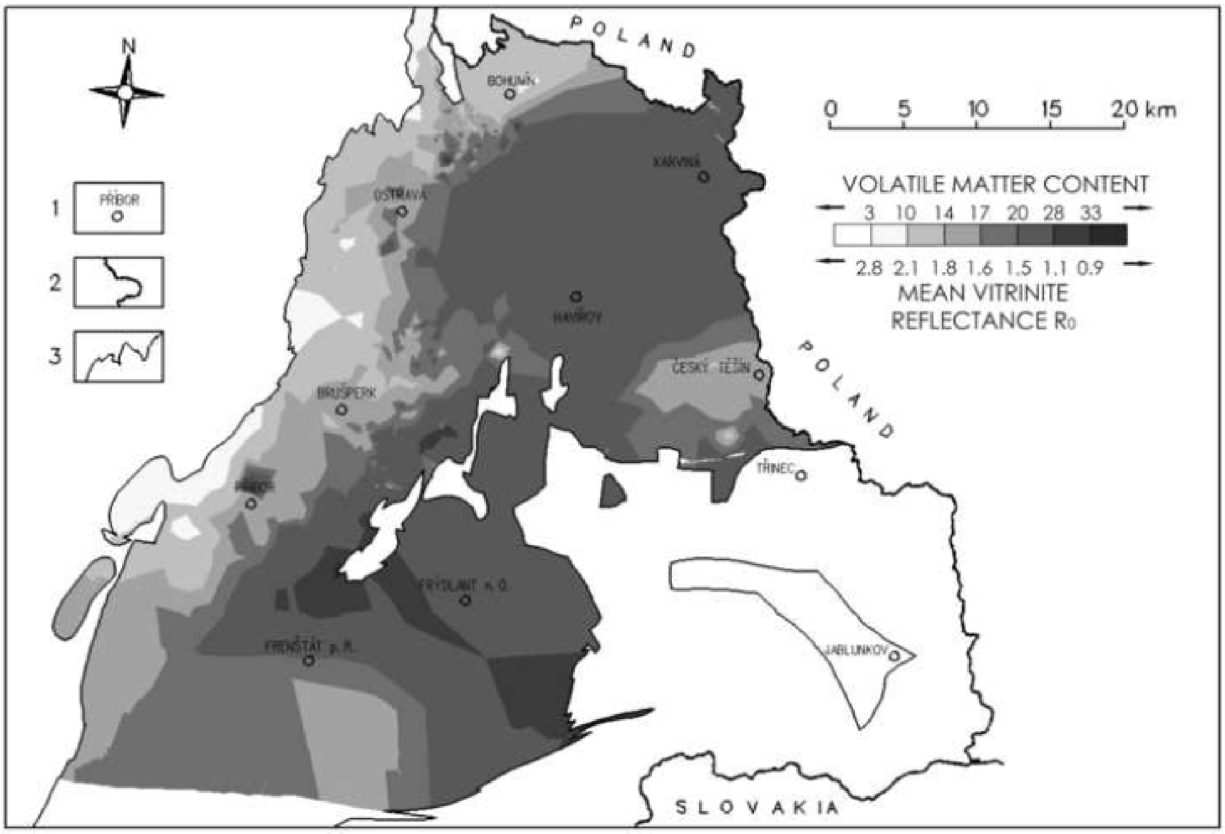

OSTRAVA FORMATION
KARVINÁ FORMATION
PORUBA MEMBER
DOUBRAVA MEMBER
JAKLOVEC MEMBER
SUCHÁ MEMBER
HRUŠOV MEMBER
SADDLE MEMBER
PETŘKOVICE MEMBER
N
state border
post-erosional boundary of the basin
occurrence of the member
0
10
20
30
40
50 km

Fig. 5



N
POLAND
POLAND
SLOVAKIA
0 5 10 15 20 km
VOLATILE MATTER CONTENT
3 10 14 17 20 28 33
2.8 2.1 1.8 1.6 1.5 1.1 0.9
MEAN VITRINITE
REFLECTANCE R0
1
2
3
BOHUMÍN
KARVINÁ
OSTRAVA
HAVÍŘOV
ČESKÝ TĚŠÍN
BRUŠPERK
TŘINEC
FRÝDLANT n. O.
FRENŠTÁT p. R.
JABLUNKOV

Fig. 6

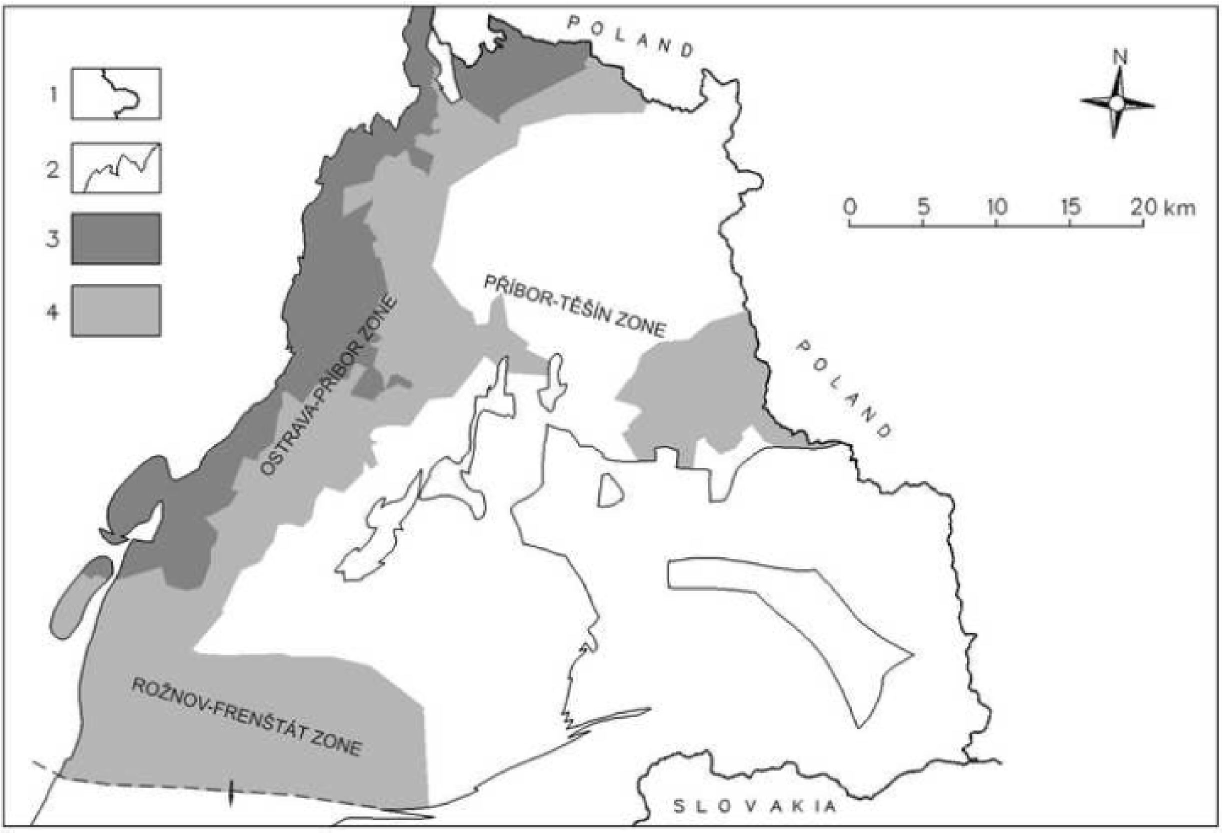
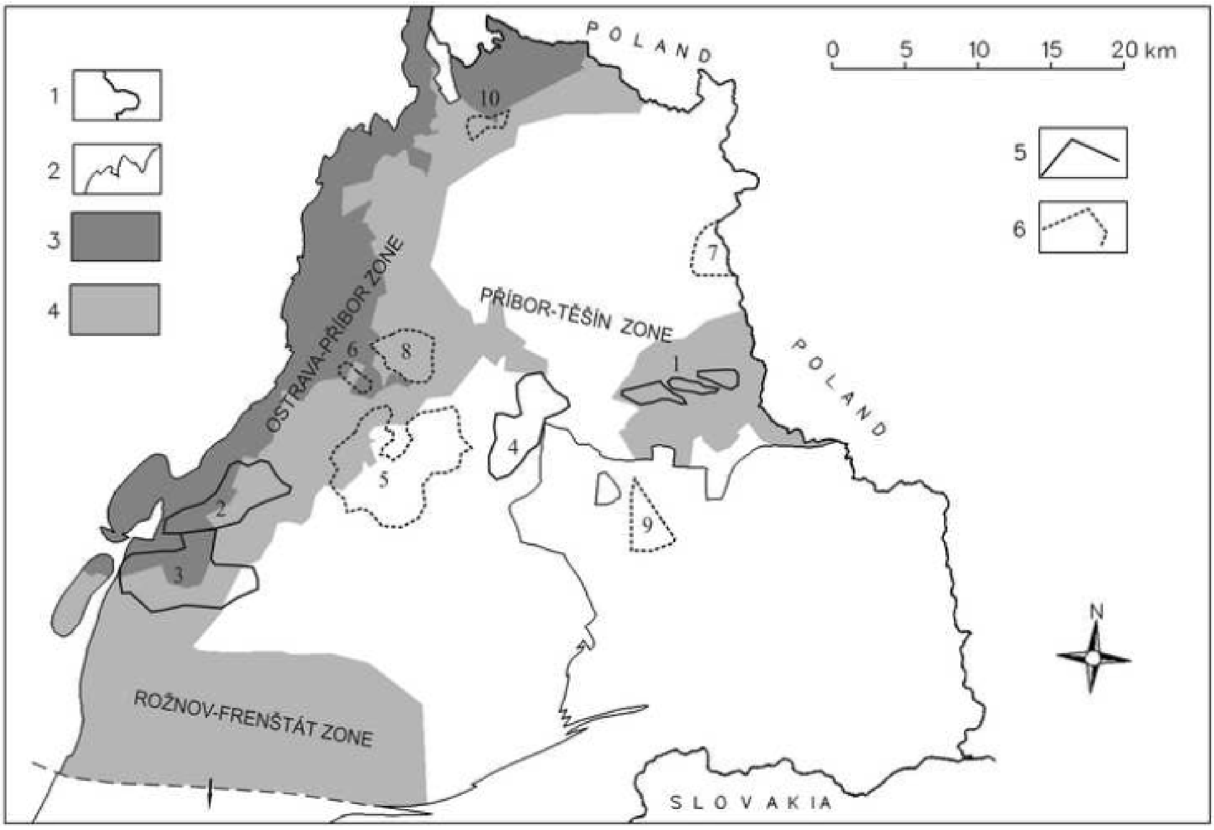

1
2
3
4
POLAND
POLAND
SLOVAKIA
N
0 5 10 15 20 km
PŘÍBOR-TĚŠÍN ZONE
OSTRAVA-PŘÍBOR ZONE
ROŽNOV-FRENŠTÁT ZONE

Fig. 7


POLAND
0 5 10 15 20 km
1
2
3
4
5
6
OSTRAVA-PŘÍBOR ZONE
PŘÍBOR-TĚŠÍN ZONE
ROŽNOV-FRENŠTÁT ZONE
POLAND
SLOVAKIA
N
1
2
3
4
5
6
7
8
9
10